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Title: **WORKER DOSE FROM NITROGEN-13 FOR THE DARHT SECOND AXIS**

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SUMMARY

During the development of the hazard analysis for the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility and the writing of a Safety Assessment Document (SAD), a concern was raised regarding radiation dose to facility workers from photonuclear activation of the Accelerator Hall atmosphere. The primary radiation hazard is from N-13 that is produced by (?,n) reactions in N-14 with the x-rays produced from the 20-MeV electron beam impinging on the beam stop material (graphite and tungsten) or on stainless steel inadvertently left in the beam pipe. The N-13 (9.96-min half-life) decays by positron emission that results in annihilation photons posing an external dose hazard to entering personnel. A first estimate using handbook techniques for continuous beam accelerators resulted an upper bound of 13 mrem per beam pulse. Personnel entering the Accelerator Hall immediately after each pulse for up to 100 pulses per day could receive 1 rem per day.

To provide a more realistic estimate of dose to personnel, N-13 production in all interior air of the Accelerator Hall was calculated with the Los Alamos MCNP code incorporating N-14 (?,n) cross sections. All the N-13 activity was artificially collapsed to a smaller volume of air near the beam stop (10 m by 7 m by 7 m), and the N-13 activity concentration in this reduced volume was used to calculate external dose using a Derived Air Concentration value for N-13, considering accelerator pulsing rates, and personnel entry times immediately after cessation of pulsing. The resulting dose per pulse for the beam stop is 0.00021 mrem and 0.42 mrem for the stainless steel accident case. For immediate entry after 100 pulses spaced 1 minute apart, the doses are 0.0031 mrem and 6.3 mrem, respectively.

1.0 BACKGROUND

During the development of the DARHT SAD hazard analysis, a concern was raised regarding neutron activation of the atmosphere near the beam stop of the second axis and the potential health impact on facility workers. The isotope ^{13}N is produced by the interaction of bremsstrahlung radiation with air nuclei. Activation of ^{13}N can occur only for accelerator electron energies above 10.55 MeV, the threshold energy of the photoneutron reaction, ^{14}N (γ,n) ^{13}N. The cross section for the ^{14}N photonuclear reaction is shown in Figure 1. Because the electron energy of the DARHT Axis 2 accelerator is a nominal 20 MeV, it is only the lower part of the cross section curve shown in Figure 1 that is important for the production of ^{13}N. The ^{13}N isotope has a half-life of 9.96 minutes.

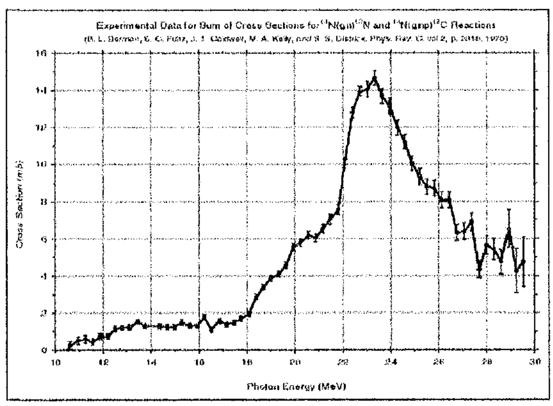


Figure 1 N-14 Photoneutron Cross Section

Initially, to provide a bounding estimate of ^{13}N concentrations and doses, a simplified calculation approach was performed (Ref. 1). This approach was based on the use of the International Atomic Energy Agency (IAEA) Handbook (Ref 2). The handbook provided the photoneutron production of ^{13}N from ^{14}N for a standardized, continuous, electron beam of 30

MeV electrons. The estimate of the number of photoneutrons was extremely high (conservative) for the intermittent, 20 MeV pulsed operation of the DARHT Second Axis.

The approach also considered that the 30-MeV electron beam impinged on an optimized tungsten target. This configuration is somewhat equivalent to the accident case for DARHT operations during which the beam is assumed to impact a stainless steel target. However, the photoneutron production rate is approximately proportional to the atomic number of the target nucleus. Tungsten has an atomic number of 74. Stainless steel is primarily iron with atomic number 26 and graphite (carbon), with atomic number 6.

Next, the handbook production rate using The Derived Air Concentration Tables in 10 CFR 835, App. C (Ref 3) was used to estimate the nuclide activity for one electron beam pulse. The total activity production for one pulse was assigned to a sub-volume of air, 154 m^3, inside the accelerator hall and near the tungsten target (beam stop). The dose per beam pulse was then calculated using this activity density as if it were a semi-infinite cloud of the same density (see Figure 2).

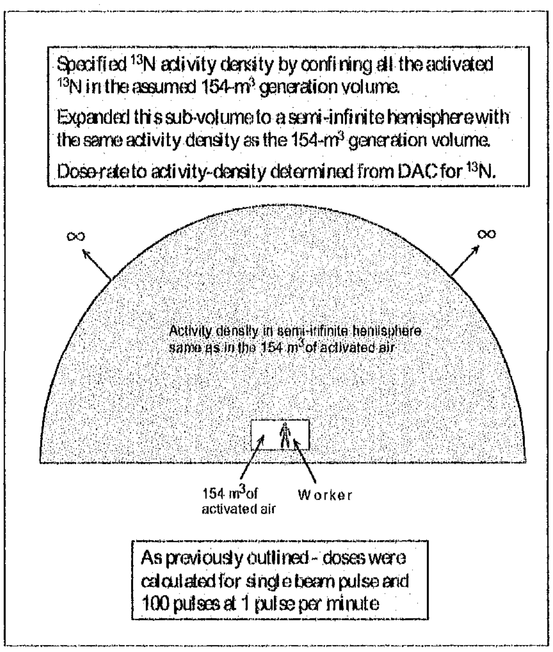


Figure 2 First Approximation

This highly conservative calculation resulted in a 13-mrem dose per electron pulse into the beam stop (assuming no air circulation, immediate worker entry and extended worker stay). The total external dose of 200 mrem was calculated based on total of 100 pulses at one pulse per minute for one hour. Both of these doses were judged to be unrealistically conservative.

It was, therefore, determined that a more realistic calculation was required in order to estimate more realistic doses for the DARHT Second Axis. This document describes a more refined calculation using the actual energy of the electron beam into a graphite target for routine operation and an accident case in which the beam impinges on a stainless steel target. The pulsed nature of the beam during the operation of the DARHT second axis is also considered in these dose estimates.

2.0 APPROACH

For this calculation, two sources of air activation were considered: 1) air activation from the beam stop consisting of a graphite absorber that stops all of the 20 MeV electrons and a tungsten alloy shield downstream from the graphite absorber and 2) air activation for an accident case for which the beam impinges on a stainless steel target (material unintentionally left in the beam tube, closed gate valve, stray beam into beam tube wall, etc.).

The photons produced in the beam stop or in the accident case interact via the photoneutron reaction with the air molecules and the resulting air activation inside the DARHT Second Axis Accelerator Hall (see Figure 3). Only those photons above the reaction threshold are involved in the reaction (see Figure 1). The primary reactions in air are shown in Figure 4. The reaction products, ^{13}N or less likely ^{15}O, decay with a halflife of approximately 10 minutes and 2 minutes respectively. The reaction products decay by positron (positive electron or $\beta+$) emission. The positive electrons have a relatively short range in air and only present a skin dose exposure. However, when the positrons are stopped in air they combine with an atomic electron and produce annihilation radiation resulting in the production of two 511 keV photons (see Figure 4). It is these photons that may represent a whole body dose for personnel who enter the accelerator hall following the pulsing of the DARHT Second Axis Accelerator.

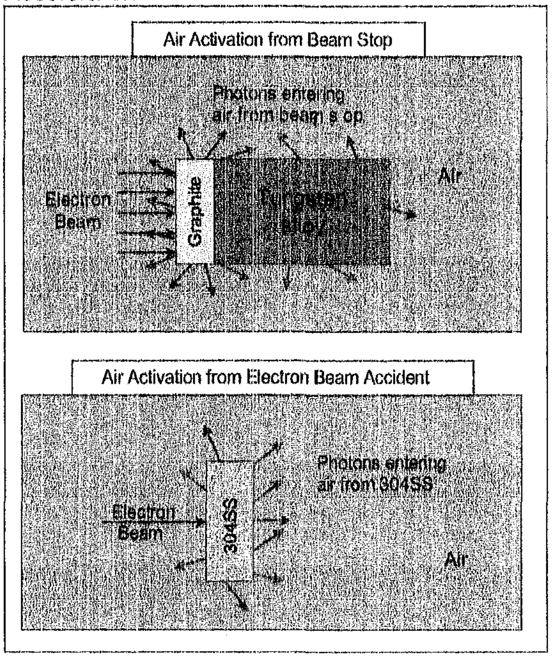


Figure 3 Sources of Air Activation

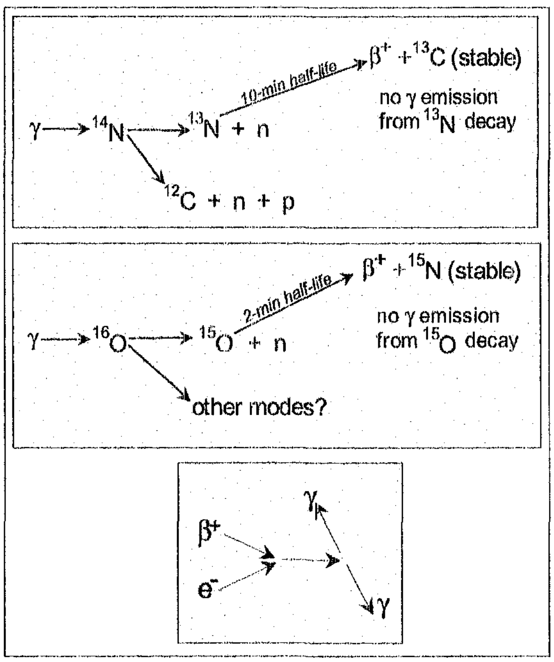


Figure 4 Primary Air Activation Modes

The analysis approach presented here begins with two types of accelerator beam interactions using a nominal 20 MeV, 2 kA electron beam and the full 2000 nsec pulse width for: 1) routine operations into the beam stop and 2) an accident case interaction with a stainless steel object (304SS).

In the first step, the Los Alamos, Monte Carlo N Particle (MCNP) radiation transport code (Ref. 4) was used to determine the number of ^{13}N and ^{15}O nuclides produced for each case of interest. This was done by using the (γ,n) production cross sections for ^{13}N and ^{15}O as photon tally modifiers. The ^{14}N (γ,n) ^{13}N cross section and the gamma energy profile resulting from 20- and 30-MeV electrons on stainless steel are shown together on Figure 5. The resulting activity production rate for the reaction at both 20- and 30-MeV electrons on stainless steel is shown on Figure 6. It is easy to see from these figures why using a 30-MeV electron energy produces such a large and conservative value for ^{13}N production.

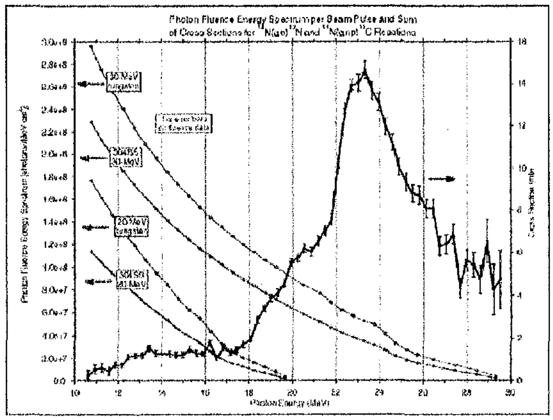
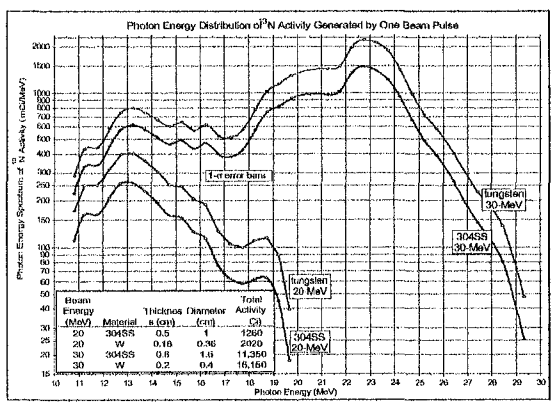


Figure 5 N-14 Cross Section and Gamma Energy Spectra



Beam Energy (MeV)	Material	Thickness (cm)	Diameter (cm)	Total Activity Ci)
20	304SS	0.5	1	1260
20	W	0.18	0.36	2020
30	304SS	0.8	1.6	11,350
30	W	0.2	0.4	16,150

Figure 6 N-13 Activity Production

The path length of the bremsstrahlung x-rays (gamma-rays) capable of initiating the ^{13}N (γ, n) ^{14}N reaction exceeds 500 meters. Therefore, the activity production calculation was performed over the entire interior air space of the accelerator hall and bull nose (approximately 3000 m^3). No photoneutron production was considered for those bremsstrahlung x-rays that escaped into the cement walls of the accelerator hall. It should be noted (see Figure 7) that the actual x-ray production reaction is heavily weighted toward the forward angles. The total photoneutron activity was determined for each pulse of electrons from the DARHT Second Axis Accelerator and for each case of interest: the beam stop and the accident case.

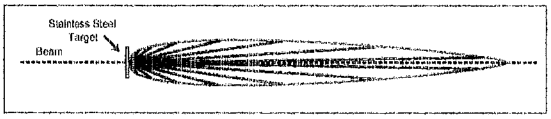


Figure 7 X-Ray Intensity for Stainless Steel

In order to simplify the second part of the calculation, the entire activity was conservatively assigned to a sub-volume of the accelerator hall near the beam stop. The assigned volume for the calculation was defined as a rectangular, cylindrical volume. The length of the cylinder was made equal to the distance from the end of the accelerator to the bull nose, the width equal to the width of the accelerator hall, and the height equal to the height of the hall (10 m. by 7 m. by 7 m.). The dose calculation was then performed using this volume.

If the ventilation system were operating, it would mix air throughout the accelerator hall, the power supply hall, and the injector room. However, for this part of the calculation, it was assumed that the ventilation system was not operating. This is a conservative assumption for personnel who will enter the hall within minutes of the operation of the accelerator. Without the ventilation system the mixing of the decay radionuclides will be caused by heat convection only. Because there are a considerable number of heat sources in the hall, it was felt that mixing would occur both in the vertical and horizontal directions.

As in the original conservative and bounding calculation discussed in the introduction of this document, the total activity that was determined in step one was used to define the activity density in the assigned volume. The Derived Air Concentration Tables were again used to specify the dose to individuals working in the area. This is a conservative and simple method for dose calculation that is often used to determine a dose to an individual at the center of the assigned volume.

Using these assumptions the dose per pulse for the beam stop is 0.00021 mrem while the accident case dose per pulse is 0.42 mrem. Table 1 shows the results for a cumulative dose that personnel might receive if entry were made to the accelerator hall immediately after operation of the accelerator for 100 pulses spaced at 1-minute intervals. The calculation was made for both the normal operation of the beam stop and for the accident case.

Table 1 Calculated Doses

<table>
<tr><th colspan="4">Dose Calculation</th></tr>
<tr><th colspan="2">Input parameters</th><th>Units</th><th>Value</th></tr>
<tr><td colspan="2">Activity Confining Air Volume
Accelerator Hall Source to Bull Nose (9m x 7m x 7m)</td><td>m^3</td><td>441</td></tr>
<tr><td colspan="2">Activity generated per pulse</td><td>mCi</td><td>1250.00</td></tr>
<tr><td colspan="2">Derived Air Concentration
(10CFR835 Appendix C)</td><td>mCi/ml</td><td>4.E-06</td></tr>
<tr><td colspan="2">Annual Dose Limit</td><td>rem</td><td>5</td></tr>
<tr><td colspan="2">Time lapse from last pulse to accelerator hall entry *</td><td>min</td><td>0.0</td></tr>
<tr><td colspan="2">Residence time in accelerator hall after entry **</td><td>min</td><td>1.00E+06</td></tr>
<tr><td colspan="2">Interval between pulses</td><td>min</td><td>1.0</td></tr>
<tr><td colspan="2">Half-life</td><td>min</td><td>9.97</td></tr>
<tr><td colspan="2">Decay constant</td><td>min^{-1}</td><td>0.069523</td></tr>
<tr><td colspan="2">Activity-Density to Dose-Rate Conversion</td><td>(mrem/min)/ (mCi/m^3)</td><td>0.010417</td></tr>
<tr><td colspan="4">* t_o = time lapse from pulse occurrence to accelerator-hall entry
** t_x = time lapse from accelerator-hall entry to exit</td></tr>
<tr><th colspan="2">Beam Stop Doses (mrem)</th><th colspan="2">Accident Case Doses (mrem)</th></tr>
<tr><td>1 Pulse</td><td>100 pulses</td><td>1 Pulse</td><td>100 pulses</td></tr>
<tr><td>.00021</td><td>0.0031</td><td>0.42</td><td>6.3</td></tr>
</table>

For the normal operation of the accelerator the ventilating system will be operating and the ^{13}N activity concentration in the beam stop area will decrease much more quickly. The ventilation system mixes air throughout the accelerator hall, the power supply hall, and the injector room.

The combined effective volume[1] of the accelerator hall, injector room, and power supply hall is approximately 6,800 cubic meters. The complete mixing of these air regions will reduce the concentration of ^{13}N in the beam stop area by the fraction (441 cubic meters)/(6,800 cubic meters) = 0.065. The ventilation system will mix these volumes at approximately 1,500 cubic meters per minute, with the result that all the volumes would be effectively mixed after about 5 minutes. No credit was taken for decay during this time.

No one is working in the accelerator hall during pulsing of the accelerator. However, because there is mixing of the air throughout the accelerator hall, injector room, and power supply hall each pulse of the accelerator delivers an increment of dose to anyone who is working on one of theses areas. Each pulse of the accelerator that strikes the beam stop will deliver a dose of approximately 0.014×10^{-3} mrem to personnel working in these areas and each accident pulse will result in a dose of approximately 27×10^{-3} mrem.

3.0 RESULTS

Using doses calculated by the MCNP radiation transport code and a simplified dose calculation model based on the Derived Air Concentration Tables found in 10 CFR 835, App. C, ^{13}N doses and activity concentrations have been estimated. These estimates are based on the following assumptions:

- All of the photons are assumed to have a high end-point energy of 20 MeV, whereas the DARHT electron beam (for interaction with stainless steel) has a broad energy distribution. The average energy is about 3 MeV in the forward direction and an end point energy is about 20 MeV. The effective energy for ^{13}N production is about 13 MeV. (For the graphite target in the beam stop, the energies are much lower.)
- A simplified and conservative relationship has been used to estimate the dose to individuals who may enter the accelerator hall immediately after the operation of the accelerator.
- The accelerator is assumed to have operated over extended periods of time such that the activity can reach saturation levels (100 pulses spaced at 1 minute intervals).
- For the accelerator entry problem, no credit has been taken for the air leakage paths into and out of the building.
- For the dose to individuals in the accelerator hall, the power supply hall, and the injector room, complete mixing of the air by the ventilation system was assumed. Each pulse of the accelerator should be included in any dose calculation for these areas.

The doses related to the operation of the accelerator into the beam stop were extremely low (microrem levels). The highest doses resulted for personnel entering the accelerator hall immediately after 100 accident case pulses (6 mrem). Because all these doses were so low no additional controls were deemed necessary to protect workers against exposure to ^{13}N.

4.0 ACKNOWLEDGEMENTS

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3. "Derived Air Concentrations (DAC) for Workers from External Exposure during Immersion in a Contaminated Atmospheric Cloud," *10 CFR 835, App. C*, January 1, 2000.
4. J. F. Briesmeister, Ed, "MCNP4B – A General Monte Carlo N-Particle Transport Code, LANL Report *LA-12625-M*, ," Los Alamos National Laboratory, March 1997.

[1] The effective volume is the room volume minus the volume occupied by items of equipment and other structures.